Physics at the Energy Frontier

Aaron Pierce
University of Michigan
Fermilab Users Meeting
June 5, 2008

MCTP

New Physics Motivations?

- Electroweak Symmetry Breaking
  - Hierarchy Problem
- Dark Matter
- Matter--Anti-Matter Asymmetry
  - EWBG--in MSSM very well defined region
- Flavor
- GUTs
- Dark Energy???

Find the Higgs...

- The first step to understanding electroweak symmetry breaking is to find the Higgs Boson.
- An experimental triumph, but will be unlikely to drastically affect how we think about the weak scale.

Beyond the Standard Model at the Weak Scale

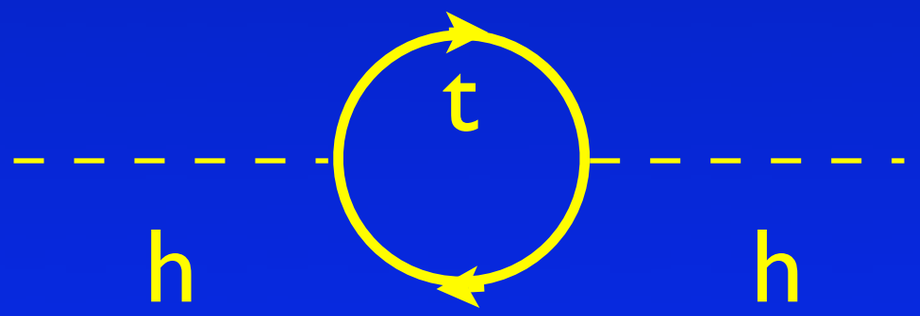
- Hierarchy Problem
- Dark Matter
- In specific scenarios, there are other motivations, but these are generic.

Natural Theories?

$$\mathcal{L} \supset -m_h^2|h|^2 + \frac{\lambda}{4}|h|^4$$

- Hierarchy Problem:

$$\Delta m_h^2 = \frac{3y_{top}^2}{8\pi^2}\Lambda^2$$



$$m_h^2 = (m_h^2)_{bare} + \text{correction}$$

Natural Theories?

- Hierarchy Problem:

Motivates most BSM Physics:

•Supersymmetry

•Technicolor

•Little Higgs

LED

•Randall-Sundrum

Naturalness?

- Two tales:
  - Electron Classical Radius
  - Cosmological Constant

E&M Correction to Electron

$$\Delta E_{Coulomb} = \frac{1}{4\pi\epsilon_0}\frac{e^2}{r_e}$$

$$m_e c^2 = (m_e c^2)_{bare} + \Delta E_{Coulomb}$$

$$0.511 = -99999.489 + 100000.000\mathrm{MeV}$$

H. Murayama
hep-ph/0002232

Positron to the rescue.

To avoid fine tuning, need something new at distances of order 10^{-13}cm

$$\begin{aligned}\Delta E &= \Delta E_{Coulomb} + \Delta E_{pair} \\ &= \frac{3\alpha}{4\pi} m_e c^2 \log \frac{\hbar}{m_e c r_e}\end{aligned}$$

$$m_e c^2 = (m_e c^2)_{bare}(1 + \frac{3\alpha}{4\pi} \log \frac{\hbar}{m_e c r_e})$$

Pion Mass Splitting

$$m_{\pi^\pm}^2 - m_{\pi^0}^2 = \frac{3\alpha}{4\pi}\Lambda^2$$

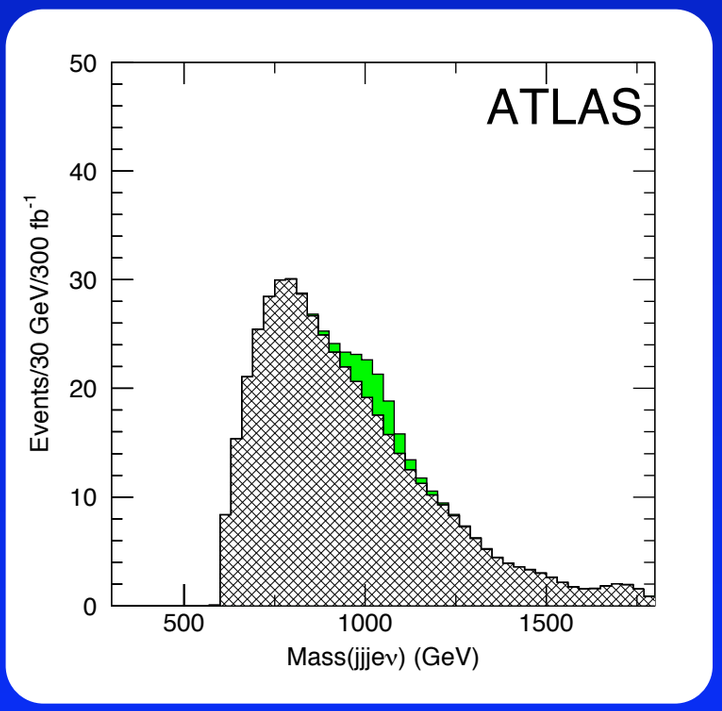
Here, the cutoff is supplied by the mass of the rho meson.

Cosmological Constant

- $\Lambda \approx (\text{meV})^4$
- This represents a fine-tuning of 120 orders of magnitude.
- Where is the new physics at the meV scale?
- Do we really understand fine-tuning?

Will we see positron/ pion story again?

- If so, then we are likely to have a host of new particles responsible for softening the divergences again.
  - Supersymmetry. (stops)
  - Little Higgs.



- G. Azuelos et al. Published in Eur.Phys.J.C39S2:13-24,2005

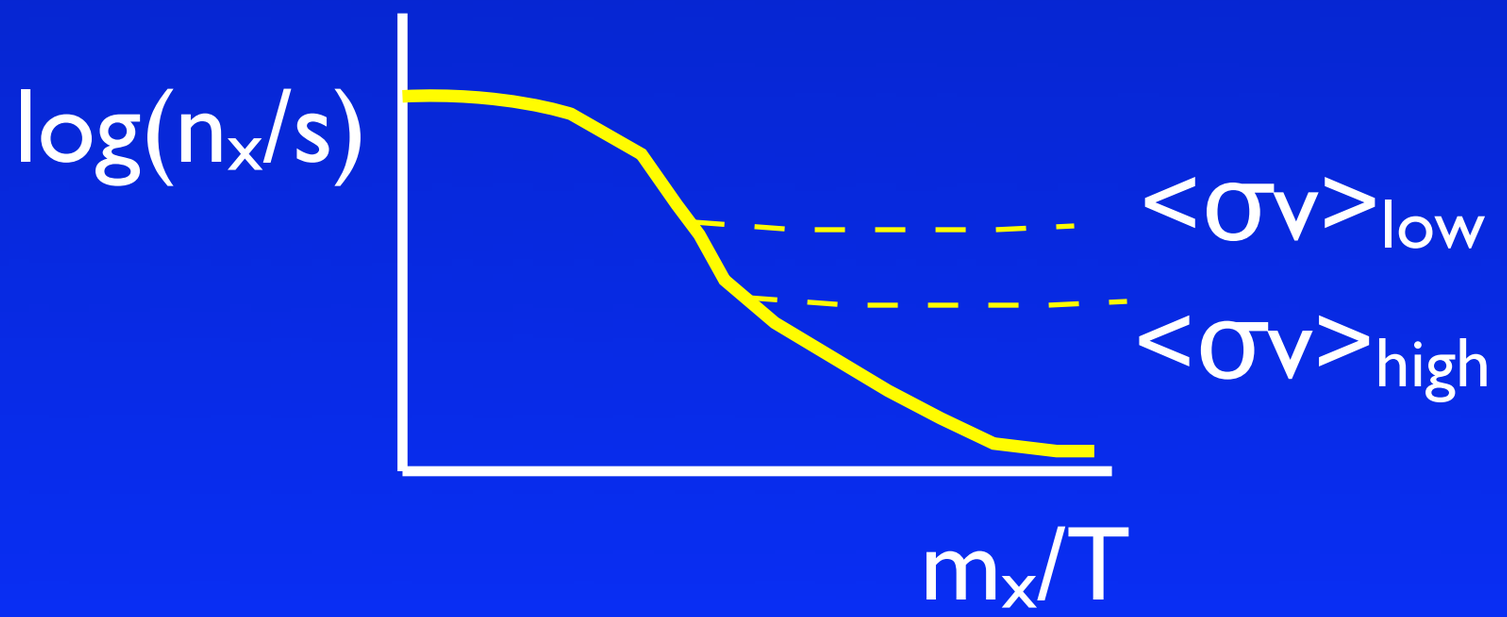
Naturalness?

If not, what can we expect at the TeV scale?
We should think about things different from Little Higgs/Technicolor/SUSY.

But What?

Dark Matter

- Second Motivation For New Physics Beyond the Standard Model at the Weak Scale:
- Thermal Relic Abundance of Dark Matter



Dark Matter

$$\Omega_{DM} = \frac{(4\pi)^2}{3}\sqrt{\frac{\pi}{45}}\frac{x_f g_S(\gamma)}{g_*^{1/2}}\frac{T_\gamma^3}{H_0^2 M_P^3 \sigma} = 0.22\,\frac{\text{pb}}{\sigma}$$

- So the exquisite mesurment of the Dark Matter Density (due to WMAP and others) points to a weak scale cross section.
- We already think the weak scale is interesting from a particle physics point of view. A cruel coincidence?

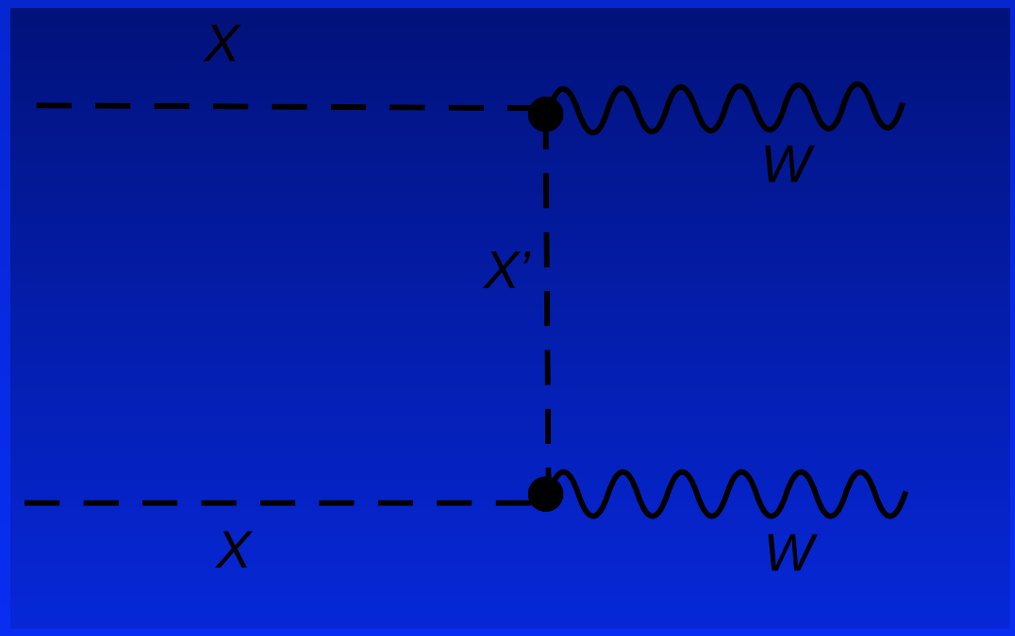
Does Dark Matter Guarantee Discoveries at Tevatron/LHC?

- No.
  - Simplest possibility: Dark Matter is non-thermal. Lee-Weinberg discussions is a coincidence.
  - Axion.
- What if Lee-Weinberg right?

- A simple possibility that won't cause the champagne to flow in Geneva:

  - An n-plet charged under SU(2) with an X⇔-X symmetry.

- Gauge Interactions Allow for Annihilation



Strumia, Cirelli, Fornengo, Tamburini

Morale:

- Dark Matter by itself won't ensure exiciting phenomenology.
- SUSY-- good dark matter candidate.
- If Dark Matter is part of a larger structure, that has TeV colored particles, then we are in business. Structure could be SUSY/UED/ Little Higgs models designed to solve hierarchy problem. What else?

SUSY Scorecard

Successes

Gauge Coupling Unification

Dark Matter

Failures

Superpartners?

Higgs Mass

FCNC (b to s gamma)

EDMS?

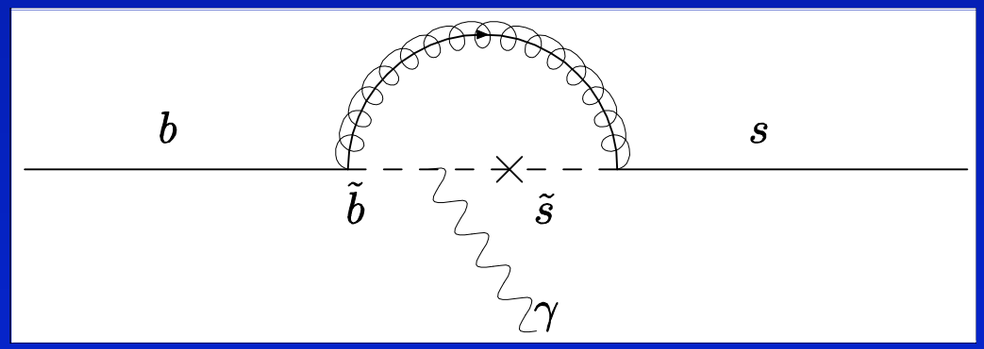
proton decay (dim 5)

Gravitinos?

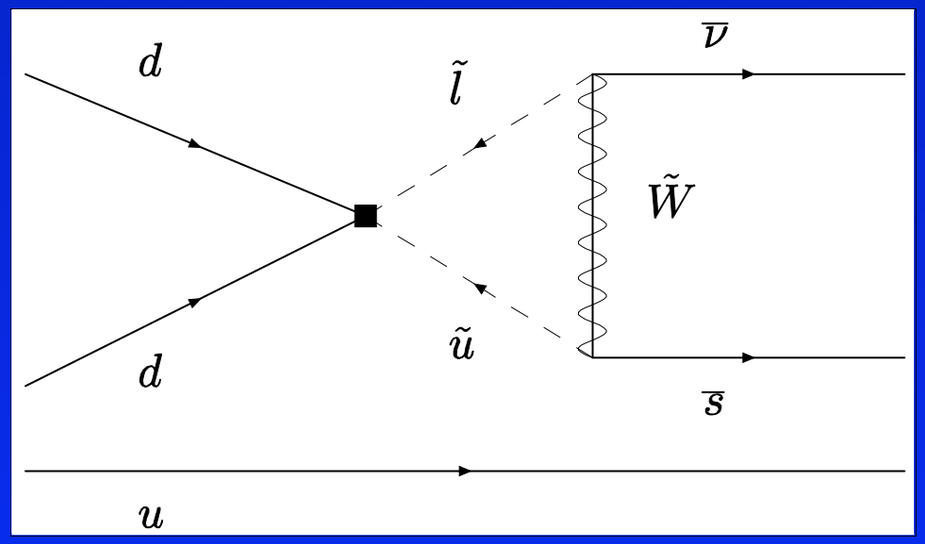
Higgs Fine Tune

CC

Trouble with Scalars



e.g. Gabbiana, et a
hep-ph/9604387



Murayama and AP
hep-ph/0108104

Gauge Coupling Unification

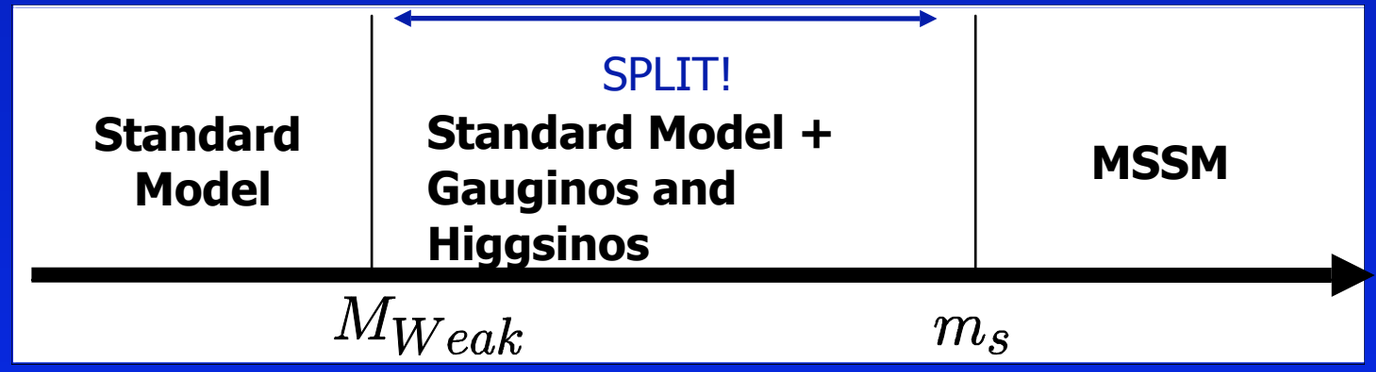
- Scalars (and SM fermions) come in complete GUT multiplets→ don't contribute to relative running
- Higgsinos, Gauginos, Gauge Bosons, Higgs Bosons are responsible for unification.

Split Supersymmetry

- No attempt is made to solve the gauge hierarchy problem.
- Prejudice: Supersymmetry has something to do with a fundamental theory.
- New Structure (SUSY) + Dark Matter⇒Weak Scale Gauginos

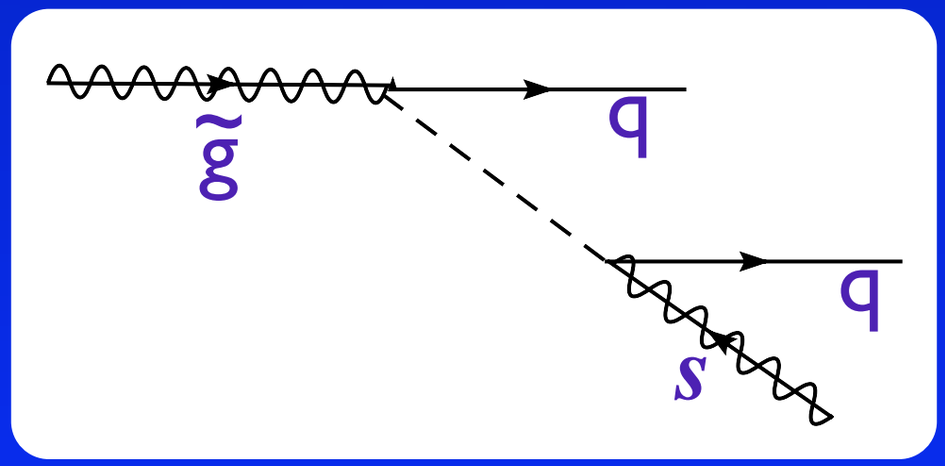
Dimopoulos, Arkani-Hamed; Giudice, Romanino

Mass Spectrum

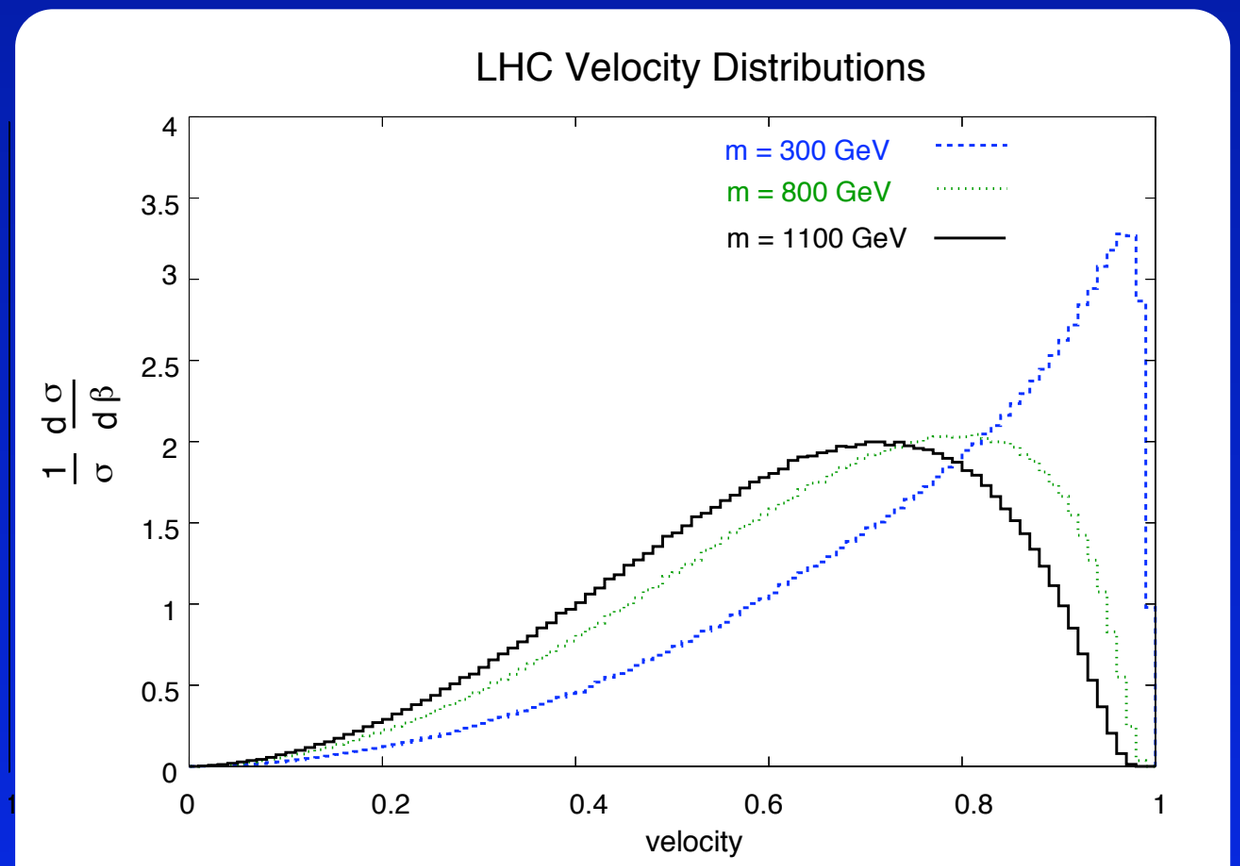


Split SUSY

- Not only electroweakinos, but Gluinos!
- Due to heavy squark mass, these can have a long lifetime, but likely less than a ~second due to BBN constraints. (Arvanitaki, Davis, Graham, AP, Wacker)



$$\frac{dE}{dx} = -\frac{4\pi\alpha^2\rho}{Am_pm_e}\frac{Zz^2}{v^2}\left(\frac{1}{2}\ln\frac{2m_ev^2}{I(1-v^2)} - v^2\right)$$



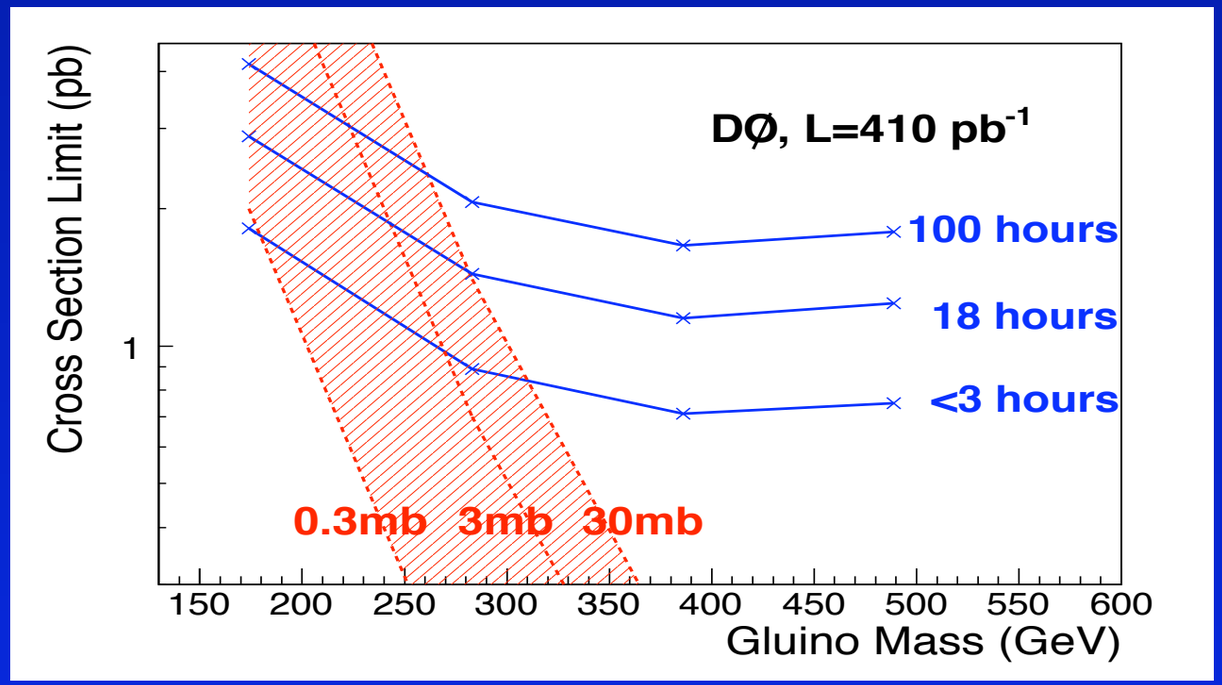
Stopping Gluinos

Stopping Gluinos

- Stopped Gluinos show up in the detector as a jet--- but not from the origin.
- Gluinos are pair produced. About 20% of the time that one gluino stops, they both do.
- Separation between "bangs" give us the gluino lifetime.

Also staus as NLSP: Feng/ Smith, Ellis/R, /Raklev/Oye, ...

A Tevatron Result

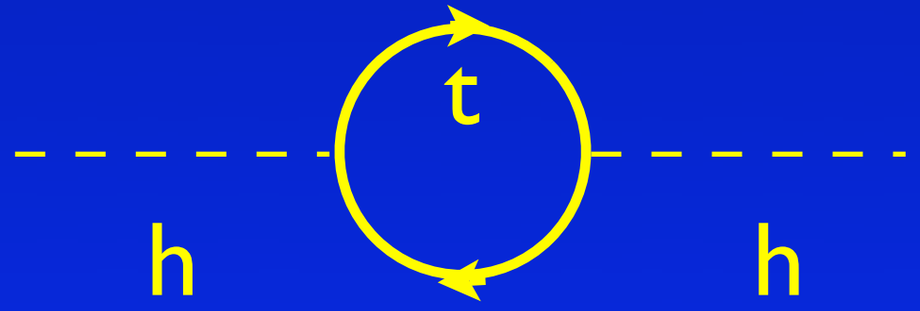


- hep-ph/07050306 (DZero)

Is the weak scale fine-tuned?

- Most have a top-partner.

$$\Delta m_h^2 = \frac{3 y_{top}^2}{8\pi^2}\Lambda^2$$



- Examples exist (e.g., Thaler and AP) where you see a top partner, (gg to TT to tops + missing) but the Higgs is still fine-tuned.

Conclusions

- Tevatron data rolling in-- surprises?
- LHC should deliver us the particle responsible for electroweak symmetry breaking.
- Naturalness-- implications for understanding CC?
- Dark Matter.